ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-WEPB06

MECHANICAL DESIGN OF THE BOOSTER TO STORAGE RING TRANSFER (BTS) LINE FOR APS UPGRADE*

J. Liu†, M. Borland, T. Clute, J. Downey, M. Jaski, U. Wienands
Argonne National Laboratory, Argonne, USA

Abstract

The APS Upgrade selected the horizontal injection scheme which requires exchanging the x and y emittances in the BTS transport line through a series of six skew quadrupoles, as well as matching the beam parameters to the APS Upgrade storage ring through two dipoles and a conventional pulsed septum. This paper presents the layout of this BTS line section in the storage ring tunnel and key components in this section including the mechanical design of dipole magnet, quadrupole and skew quad magnets, the vacuum system, the diagnostics system, and the supports. Finally, detailed mechanical design of this BTS line section in modules and some consideration for fabrication and installation are addressed.

INTRODUCTION

The Advanced Photon Source Upgrade Project (APS-U) is planning a storage-ring upgrade that will reduce the electron-beam emittance by a factor of ~75 [1]. This ultra-low emittance is achieved by replacing the present storage ring lattice with a hybrid multi-bend achromat (MBA) lattice [2, 3]. The MBA lattice will increase the x-ray coherent fraction by two orders of magnitude and decrease the horizontal source size by a factor of ~20. The upgrade project adopts a horizontal injection scheme using a pulsed septum and fast stripline kickers for swap out injection and extraction [4]. The horizontal injection requires exchanging the x and y emittances in the BTS transport line [5]. To minimize change to the booster side of the BTS line, the section of BTS line on the SR side is redesigned and will be replaced with new a layout and components.

The scope of this paper mainly focuses on the mechanical design of the section of BTS transfer line located in the SR tunnel, including Lattice design, magnets design, vacuum system design, diagnostics design, and modular design of the whole section. Details of the designs are described in the following sections.

DESIGNS

The mechanical design of the BTS section is based on a beam physics design. The beam physics design developed for the APS-U is a horizontal injection scheme. The scheme requires exchanging the x and y emittances using six skew quadrupoles, as well as matching the beam parameters to the APS-U storage ring. After iterative processes of lattice and magnetic designs, the parameters were finalized for the dipole, quadrupole, and skew quadrupole magnetic designs. The mechanical design was conducted from magnetic design according to the magnetic model. All new magnet designs are consistent with the SR magnet designs to take advantage of the work and experience with the SR magnets.

Lattice of BTS Section

Figure 1 shows the final layout of the BTS section. This section includes a total of 16 quadrupoles, 2 dipoles, 3 vertical correctors and 2 horizontal correctors. Of the 16 quadrupoles, 5 of them - BTS:BQ1 to BTS:BQ5 - are existing APS BTS magnets that will be reused. BTS:EXQs are skew quadrupoles and BTS:CQ1-3 and BTS:DQ1,2 are new quadrupole magnets. Skew and normal quadrupole magnets are of the same geometry but oriented in normal and skew orientation to reduce engineering work. All the new normal and skew quadrupoles include horizontal and vertical corrector trims. They will be operated at different parameters. BTS:BB1 and BTS:CB1 are new dipoles, but identical dipoles. BV1-3 are vertical correctors and BH1-2are horizontal correctors. All the correctors are existing APS BTS magnets that will be reused. The locations of BPMs and Flags are also identified in Fig. 1. Between sections BTS:EXQ1B and BTS:BV3 will be the duck-under to allow passage across the BTS section.

Magnet Design

Table 1 lists the parameters of the BB1/CB1 dipoles in the BTS section on the SR side. Table 2 lists the parameters of the new skew and normal quadrupoles.

The mechanical design of the dipole magnet is shown in Fig. 2. The dipole yoke takes a three-piece design. Four taper dowel pins holes are drilled and reamed on pilot holes after aligning and clamping the yokes to the backplate. This method gives cost effective control of pole gap tolerance with high repeatability. It has been tested successfully on our SR dipole magnets.

Dipole coils are made of water-cooled hollow copper conductor of SQ 6 ± 0.1 mm with 3.5 ± 0.1 mm I.D. Each coil is made of 5 pancakes, with each pancake having two five-turn layers.

* This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility at Argonne National Laboratory and is based on research supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
† jieliu@aps.anl.gov

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-WEPB06

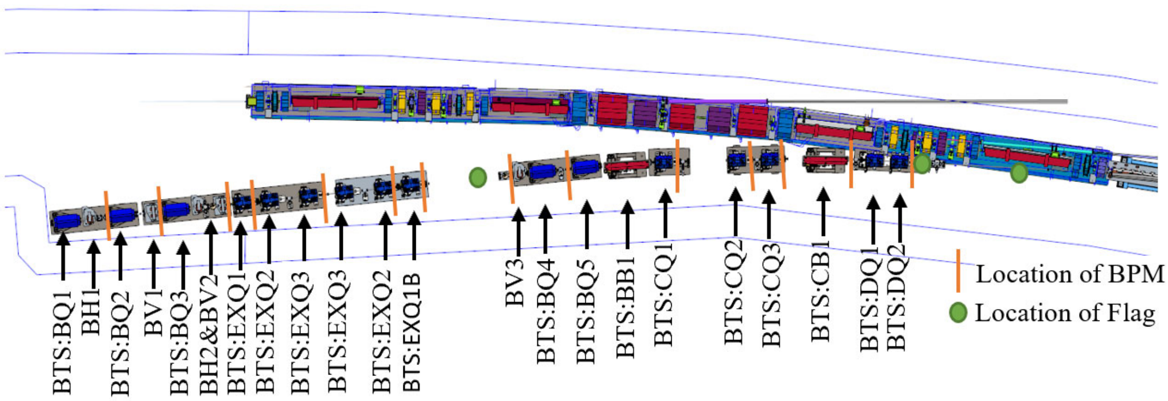

Figure 1: Layout of the BTS section in SR tunnel.

Table 1: BB1/CB1 Dipole Parameters

Parameter	Value	Unit
Length	1.18	m
Angle	0.07846	radian
B	-1.4	T
Critical energy	33.9	keV
SR Power	0.002023	W

Table 2: Normal and Skew Quadrupole Parameters

Parameter	Value	Unit
Length	0.482	m
Aperture	26	mm
Max required integrated gradient	27.9	T
Min required integrated gradient	7.8	T
Max integrated corrector	0.0077	T-m

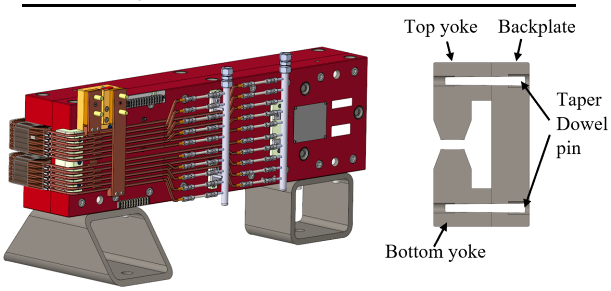

Figure 2: Mechanical design of the BB1/CB1 dipole.

Figure 3 shows the mechanical design of the normal and skew quadrupoles. These quadrupoles utilize the same patented 8-piece design as the SR quadrupoles [6]. This design can achieve high field quality and be cost effective because it aligns the pole tips within tight tolerance and then align the yoke accordingly. Taper pin holes are drilled and reamed on pilot holes after aligning and clamping the yoke assembly. Two taper pins are used between the two top quadrants and two bottom quadrants. Two taper pins are used between the top half and bottom half. Test results have shown that the taper pins can achieve high repeatability within 25 µm. Coils are made of water-cooled hollow copper conductor of SQ 6 ± 0.1 mm with 4 ± 0.1 mm I.D.

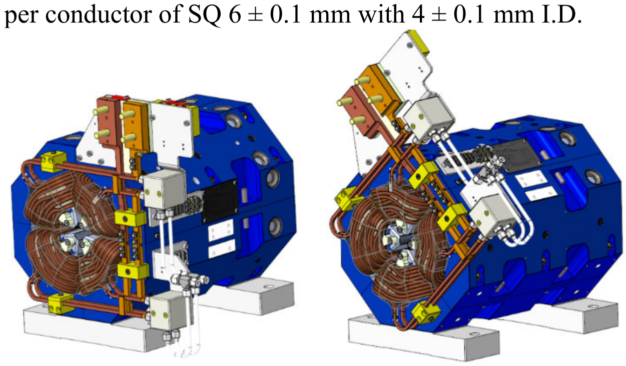
Figure 3: Mechanical design of the normal/skew quads.

Vacuum Systems

The BTS line overall length is 27.4 m. All the vacuum chambers are made of electro-polished stainless steel with CF flanges. The chamber ID is 22 mm in the quadrupole sections, 12 mm from before DLMB: BM1 to the septum magnet. Target pressure is lower than 5 x 10^{-9} Torr as read at the ion pumps. There will be one gate valve installed at each end of the section and a gauge tree near the connection of the BTS line to the storage ring. Gate valves are of the All-Metal variety to avoid radiation damage to a Viton/buton seal. The gauges are hardened against radiation with remote electronics and are capable of measuring into the 10^{-13} torr range. A total of seven pumps of 45 l/s will be installed at various sections to achieve the desired pressure.

Diagnostics

Three type of Diagnostics will be installed in this BTS section: Beam Position Monitor (BPM), beam profile monitor (Flag), and Fast Beam Loss Monitor (BLM). The locations of BPMs and Flags are shown in Fig. 1.

There is a total of 14 4-button BPMs. The mechanical design of the BPM is shown in Fig. 4. The BPM is made of four welded electrode feedthroughs in a SS holder. The electrode feedthroughs are the same as the standard BPMs used in the storage ring vacuum system of APS-U [7]. There is one welded bellow connected to one side of the BPM to accommodate thermal expansion. There are three survey cups on the feedthrough holder to allow proper alignment of the BPMs.

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-WEPB06

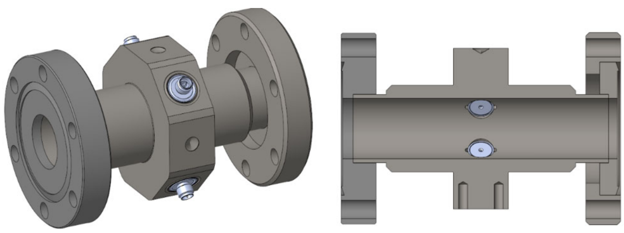

Figure 4: Mechanical design of BPM.

There will be one Flag in the zero-dispersion regions after the emittance-exchange section. There will be two Flags near the very end of the BTS line between the septum and the BTS: CB1 dipoles. The Flags will be reused from the existing BTS.

There will be a fast, fiber-based BLM installed in the BTS for localizing losses as well as measuring loss levels along the BTS line. The fiber bundle will run the length of the transport line, ending just upstream of the S39B:Q2 magnet. The fiber bundle will be as close to the beam pipe as possible, ideally being attached directly to the vacuum chamber. A photomultiplier tube at the upstream end of the fiber bundle will be used to establish the loss location by timing the arrival of pulses using an oscilloscope. Integration of the signal will allow determining total losses. The primary use of the BLM is to diagnose issues with poor transfer efficiency during commissioning and operations and to assist in BTS steering and optimization.

Support Tables

All support tables are designed to allow ±12 mm component adjustment in x, y, and z directions. The rms vibration for frequencies above 0.1 Hz is less than 1 µm to keep the effective emittance of the injected beam from being inflated by more than a negligible 1 nm.

Module Assembly

BTS components are grouped into 12 modules for effective module assembly and installation, as shown in Fig. 5. All components will be pre-assembled into modules. The magnets will be aligned to each other within each module. The modules will then be fiducialized and delivered to the installation team to be installed. Table 3 lists the alignment requirements. Fig. 6 shows module 3 with all components in the module. Each module begins or ends with a bellow to facilitate easy connection of the vacuum chamber after installation.

Prior to shipment and storage, the vacuum system of each module will be blanked off and backfilled with ½ psig dry nitrogen. All water-cooling lines will be blown dry and capped off. All components at risk of damage due to vibration or shocks less than 3g will be supported and protected for transportation.

Power Supply and Control Systems

All power supply systems, diagnostics electronic systems, and control systems will be installed at the dedicated places close to sector 38 and 39. All cables will drop from an overhead cable tray to the components below. All magnet cooling water lines will connect with headers overhead.

CONCLUSION

The APS BTS transfer line section in the SR tunnel needs be replaced to facilitate horizontal injection. All design work and the final design review have been completed. The APS-U BTS section is now proceeding through the procurement and fabrication phases. With all the experience gained from SR magnets and other components, this work on the BTS does not pose much risk to the project.

Table 3: Alignment Requirements

Parameter	Value	Unit
Fidualization uncertainty for each magnet module, transverse	50 rms	µm
Align magnet-to-reference line within a module, transverse	100 rms	µm
Module fiducials to reference line, transverse	100 rms	µm
Module alignment to adjacent modules, transverse	100 rms	µm
Alignment magnet to magnet within a module, longitudinal	0.5 rms	mm
Alignment module to adjacent magnet modules, longitudinal	0.5 rms	mm

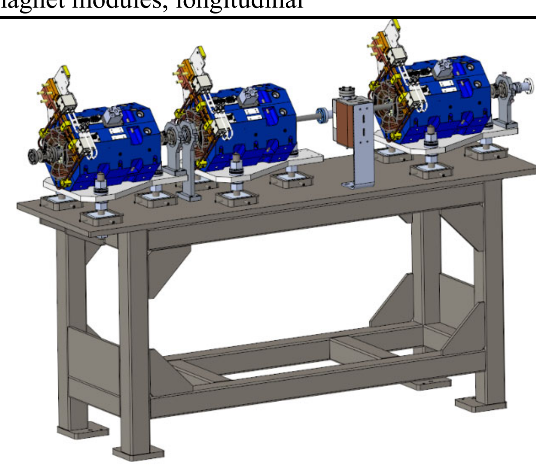

Figure 6: Mechanical design of the module 3.

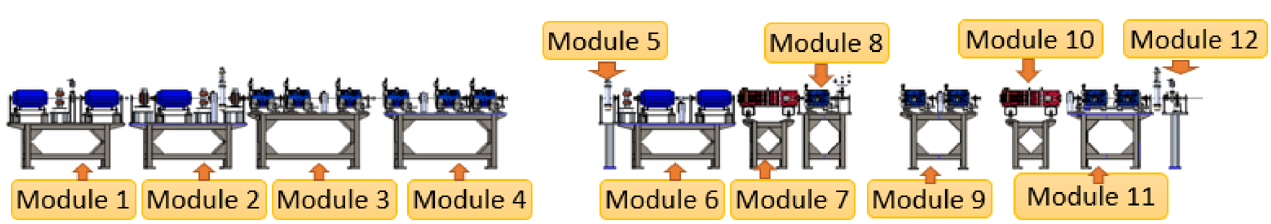

Figure 5: Modular layout of the BTS section.

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-WEPB06

REFERENCES

[1] T. Fornek, "Advanced Photon Source Upgrade Project Final Design Report," APSU-2.01-RPT-003, 2019. https://doi.org/10.2172/1543138

[2] L. Farvacque *et al.*, "A low-emittance lattice for the ESRF," in *Proc. IPAC'13*, Shanghai, China, May 2013, paper MOPEA008, pp. 79-81.

[3] M. Borland *et al.*, "Lower Emittance Lattice for the Advanced Photon Source Upgrade Using Reverse Bending Magnets," i*n Proc NAPAC'16*, Chicago, USA, October 2016, pp. 877-880. doi:10.18429/JACoW-NAPAC2016-WEPOB01

[4] L. Emery, M. Borland, "Possible long-term improvements to the Advanced Photon Source," in *Proc. PAC'03*, Portland, OR, USA, May 2003, paper TOPA014, pp. 256-258.

[5] P. Kuske and F. Kramer," Transverse emittance exchange for improved injection efficiency," *in Proc. IPAC'16,* Busan, Korea, May 2016, pp. 2028-2031. doi:10.18429/JACoW-IPAC2016-WEOAA01

[6] M. Jaski, J. Liu, A. Donnelly, J. Downey, J. Nudell, J. Animesh, "Eight piece quadrupole magnet, method for aligning quadrupole magnet pole tips," United States: N.p, No. 9,881,723, 2018. https://www.osti.gov/servlets/purl/1418829

[7] J.A. Carter *et al.,* "Final Design of the APS-Upgrade Storage Ring Vacuum System," in *Proc. NAPAC2019*, Lansing, MI, USA, Sep. 2019, paper TUYBB3, pp. 315-317. doi:10.18429/JACoW-NAPAC2019-TUYBB3